LEPTON AND QUARK ASYMMETRIES

V. Ciulli

Istituto Nazionale di Fisica Nucleare, Sezione di Firenze

Abstract

Lepton and quark asymmetries at Z boson peak are a powerful means to test the couplings of the Z boson to fermions. The measurements performed at LEP and SLC colliders are reviewed, and their impact on the determination of the electroweak mixing angle is presented.

1 Asymmetry parameters

The asymmetries of fermions in e^+e^- collisions at the Z peak are related to the vector and axial-vector couplings of the Z boson to fermions, $g_{\rm Vf}$ and $g_{\rm Af}$, or, more precisely, to the asymmetry paramater

$$A_{\rm f} = \frac{2 g_{\rm Vf} g_{\rm Af}}{g_{\rm Vf}^2 + g_{\rm Af}^2}\,.$$

In particular, the left-right asymmetry, $A_{\rm LR}$, i.e. the difference between the cross-sections for left/right polarised electrons divided by the total cross-section, is equal to A_e. For unpolarised beams instead, the polarisation of the outgoing fermions f, $\mathcal{P}_{\rm f}$, is equal to $-A_{\rm f}$. Finally the forward-backward asymmetry, $A_{\rm FB}^{\rm f} = \frac{3}{4} A_e A_{\rm f}$, can be measured from the distribution of the angle between the direction of the outgoing fermion f and the incoming electron, and it is the only asymmetry which does not require a polarisation measurement. From each of these measurements the parameter $\sin^2\theta_{\rm eff}^{\rm lept}$, related to the weak mixing angle of the Standard Model, can be extracted.

2 Measurements at LEP and SLC.

A total of 17 millions Z decays into hadrons and leptons have been collected altogether by the four experiments at LEP collider between 1990 and 1995. This huge statistics allowed to measure forward-backward asymmetries of all leptons and of heavy quarks, and the polarisation of the τ lepton [1]. Much less events, about 500000 Z bosons, were collected in 1993-1998 by the SLD experiment at the SLC collider, but by means of the 80% longitudinally polarised electron beam, they allowed a very precise measurement of A_{LR} and of A_{b} [1].

If lepton universality is assumed, the parameter A_ℓ can be measured from A_{LR}, the forward-backward lepton asymmetries, A^ℓ_{FB}, and the τ polarisation, $\mathcal{P}_\tau$. Results from these measurements are shown in Table 1 and they are all in agreement.

The parameters A_{b} and A_{c} are measured directly by SLD from the corresponding A_{FB}'s with left and right polarised electron beam. It is, however, possible to extract them from $A^{\mathrm{b}}_{\mathrm{FB}}$ and $A^{\mathrm{c}}_{\mathrm{FB}}$ measured at LEP, and A_ℓ. Results for A_{b} and A_{c} are shown in Table 2, and compared to the predictions from the Standard Model fit. A discrepancy by 2.6 standard deviations is observed between the measured A_{b} and the Standard Model prediction, when combining LEP and SLD results. No discrepancies are observed instead for A_{c}. In Fig. 1 the results are shown in the (A_ℓ,A_{b}) plane. The measured $A^{\mathrm{b}}_{\mathrm{FB}}$ is compatible with A_{b} measured by SLD and the Standard Model, but the resulting prediction for A_ℓ is significantly lower than the measured value.

The combination of all the asymmetry measurements yields $\sin^2\theta^{\mathrm{lept}}_{\mathrm{eff}} = 0.23148 \pm 0.00017$. But, as shown in Fig. 2, the most precise results, those from A_{LR} and $A^{\mathrm{b}}_{\mathrm{FB}}$, differ by about 2.9 standard deviations. Altogether, the χ^2/d.o.f. of the fit is 10.2/5, which has 7% probability to occur.

Table 1: Results for A_ℓ from LEP (top) and SLD (bottom).

	A_ℓ	Cumulative average	χ^2/d.o.f.
A^ℓ_{FB}	0.1512 ± 0.0042		
$\mathcal{P}_\tau$	0.1465 ± 0.0033	0.1482 ± 0.0026	0.8/1
A_{LR}	0.1513 ± 0.0021	0.1501 ± 0.0016	1.6/2

Table 2: Results for A_b and A_c.

	LEP $A_\ell = 0.1482 \pm 0.0026$	SLD	LEP + SLD $A_\ell = 0.1501 \pm 0.0016$	SM fit
A_b	0.894 ± 0.022	0.922 ± 0.020	0.901 ± 0.013	0.935
A_c	0.639 ± 0.034	0.670 ± 0.026	0.656 ± 0.021	0.668

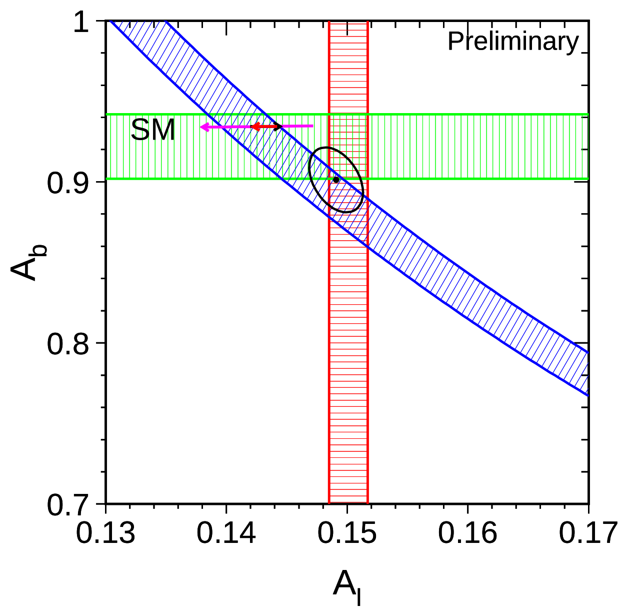

Figure 1: Comparison of the measurements of A_b, A_FB^b and A_ℓ. Bands of ± 1 standard deviation are shown, together with the 68% confidence level contour for the joint analysis. The arrows pointing to the right and to the left show the variation in the Standard Model prediction for varying m_t in the range 174.3 ± 5.1 GeV/c^2 and m_H in the range 300^{+700}_{-186} GeV/c^2, respectively.

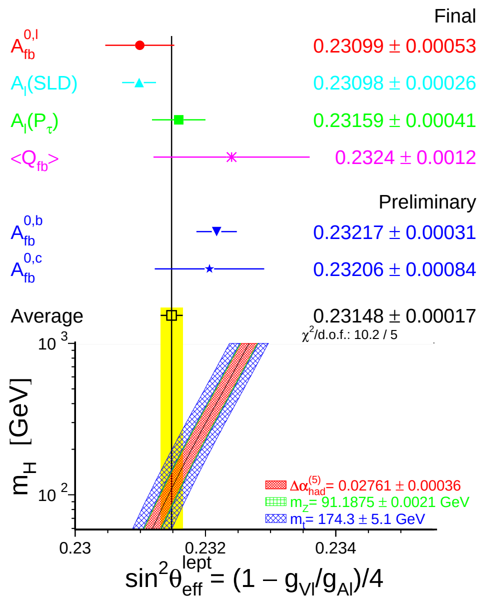

Figure 2: Results for $\sin^2\theta_{\rm eff}^{\rm lept}$. The Standard Model prediction is also shown.

3 Conclusions

An impressive precision has been reached on $\sin^2\theta_{\rm eff}^{\rm lept}$ from the asymmetry measurements at the Z peak. A three sigma discrepancy, however, is still present between $A_{\rm LR}$ and $A_{\rm FB}^{\rm b}$. In general lepton measurements are in agreement with each other but not with quark measurements, even though the discrepancy would be below two sigmas if LEP measurements only were considered. A deviation of the Z couplings to the quarks which shows up only in these measurements is unlikely. Only a large systematic effect, either common to all LEP experiments or much larger than the estimated systematic uncertainty on $A_{\rm LR}$, could explain such a difference, if it is not a statistical fluctuation. Finally, it is worth noticing that only few measurements are still preliminary, therefore it is likely that this discrepancy will not be solved before the next generation of experiments at future colliders.

References

[1] The LEP Electroweak Working Group and the SLD Heavy Flavour Group, "A Combination of Preliminary Electroweak Measurements and Constraints on the Standard Model", LEPEWWG 2003-01, 8 April 2003